Impact of Demand-Side Retrofit on the Energy Savings at the Universiti Teknologi Malaysia

M. S. Majid, Member F. M. Taha, Member
Faculty of Electrical Engineering (FKE)
Universiti Teknologi Malaysia
Skudei, Johor Bahru 80990, Malaysia

N. M. Maricar, Student Member S. Rahman, Fellow
Alexandria Research Institute, Virginia Tech
206 N Washington St, Suite 400
Alexandria, VA 22314, USA

Abstract: This paper consists of a case study in retrofitting the library building at the Universiti Teknologi Malaysia primarily for demand side management applications involving lighting and air-conditioning systems. The data acquisition and monitoring system was installed in the early stages of the work. Its function was to monitor, record and store the measured data within the library. Lighting retrofit included replacing common magnetic ballasts with electronic ones, installing high quality reflectors and energy-saving 26-mm fluorescent tubes. This provided the opportunity for delamping from the original 3-tube fixture to a single tube. Air-handler retrofits included modifications to or replacements of the motors, fans, belts, and other relevant equipment, which reduced the energy usage of the system and improved the comfort level for the library patrons. The retrofit exercise generated savings of more than 300 kW of peak load, which is more than 39% of the total building load. More than 70% of these savings came from lighting retrofits. And with 378 hours of operation of the library per month, the payback was less than 2 years.

Keywords: Air conditioning, Energy management, Energy measurement, Lighting, Power demand.

I. INTRODUCTION

This paper consists of a case study in retrofitting the library building at the Universiti Teknologi Malaysia (UTM) primarily for demand side management applications involving lighting and air-conditioning systems. The objective of this work is to show the retrofit activity that has been done in three phases to get a measured savings from a 4-level library, 179,500 square feet (16,676 square meter) space, located in a tropical country Malaysia, Southeast Asia. The outside temperature variation in the area is between 26°C to 35°C with humidity ranges from 90% to 100%.

The whole project took four years to complete including three years to reach an agreement between the vendor and the university administration, and one year to install monitoring equipment, data acquisition system, replacing the ballast, and changing the air-handler motor.

The retrofit works seeks to offer improvement of the library comfort level to the management, while at the same time reducing the energy consumption, which leads to reduced expenses and contribution to the reduction of greenhouse gas emission.

II. METHODOLOGY

The data acquisition and monitoring system was installed in the early stages of the work. Its function was to monitor, record and store the measured data within the library. The software is a useful tool to analyze and compare the collected data on a time scale basis. The hardware installed included thermistors, kW transducers and flowmeter. Lighting retrofit included replacing the common magnetic ballast with electronic ballast, installing high quality reflectors and energy savings 26-mm fluorescent tube. The use of the reflectors provided the opportunity for delamping from the original 3-tube fixture to a single-tube one. Apart from that, the replacement tubes generate white light which has a higher output in red color spectrum resulting in more reading comfort due to lesser glare.

Air-handler retrofits included modifications or replacements for the motors, fans, belts, and other relevant equipment, which reduced the energy usage of the system and improved the comfort level for the library patrons. In evaluating the energy saving measures from this retrofit, we were estimating the difference between the amount that would have been consumed in the absence of the retrofit and the amount actually consumed, i.e.

$$\text{Savings} = (\text{kWh})_{\text{"would have"}} - (\text{kWh})_{\text{actual}} \tag{1}$$

A complete analysis includes the metered electricity consumption data (for the library-use only) from before and after the installation of retrofit measures, data on building characteristics, and what would have been consumed. To get the estimates on what would have been consumed, we used the metered data readings before the retrofit and confirmed with the library management as the witness. Apart from this, the 1-minute interval data is collected from data acquisition monitoring system. Since the climate would not changed drastically throughout the year, we agreed to take that as a uniform price at all months of the year.

III. DATA ACQUISITION AND MONITORING SYSTEM

In the beginning on 1993, the first monitoring system *Enerlyst* was installed at UTM library to acquire the necessary data for energy efficiency retrofit. The key features of *the Enerlyst Software* are as follows:

- Monitoring of up to maximum of 576 electrical data logger points, 1024 HP high precision datalogger measured points and 64 calculate computed points.
- User friendly operator interface.
- Easy expansion of monitoring points.
- Compaq database storage in binary files with an efficient historical interface to view monthly, weekly, daily data for 1-minute resolution.

The *Enerlyst* HP 3852A Data Acquisition unit (DAC) is connected to the 12 electrical points from the output of kW transducers. To check the readings, instant measurement using HIOKI instrument of accuracy ±1% from Jan 19, 1993 to Feb 16, 1993 has been compared with HP-DAC readings from Apr 3, 1993 as described at Table 1. Percentage error of total kW is (811.7 – 790.7)/ 790.7 = 2.7%, which is within the acceptable tolerance of ±5%.

The second system *Enflex* data acquisition system was installed at the end of 1994. The *Enflex* DAC is used for capturing Air Handling Unit (AHU) off-coil (after the coil) and on-coil (before the coil) temperature, chilled-water supply and return temperature, and library return-air dry-bulb (DB) and wet-bulb (WB) temperatures. Fig. 1 shows the AHU room and adata monitoring point configuration. The off-coil and on-coil temperature, chilled-water supply and return temperature are used for determining the AHU operating condition, including checking the condition of control valve at the chilled-water pipe. The DB and WB return air temperatures are used for determining the comfort level in the library. There are 12 AHUs, which distributed 4 AHUs on each floor.

TABLE 1
CHECKING THE *ENERLYST* SYSTEM ACCURACY.

Descriptions	*Enerlyst HP-DAC (kW)*	*HIOKI Instant Measurement (kW)*
Mosque	13.6	13.6
Electrical Riser 1	76.1	82.4
Electrical Riser 2	71.8	80.8
Electrical Riser 3	101.1	116.9
Essential Board	63.0	63.0
A/C Riser 1	54.0	51.2
A/C Riser 2	58.5	59.1
A/C Riser 3	54.6	56.8
A/C Switch Board	298.0	287.9
Chiller 1	177.0	171.5
Chiller 2	0.0	0.0
Total	790.7	811.7

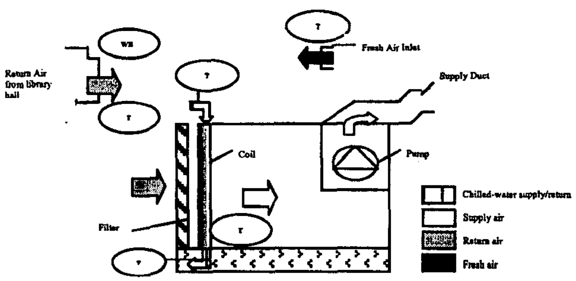

Fig. 1. AHU data acquisition points.

Both systems are still acquiring data from electrical riser points and Air Handling unit points. Additional points are added to get chiller water supply flow and pressure points and combined with the *Enflex* system. These points are for future use to retrofit chiller plant, that consists chiller sizing and pump selection to find the right load for the library.

IV. LIGHTING RETROFIT

The primary advantages of retrofit lighting with new lighting technologies are:

1. Lower long run costs of energy savings.
2. Maximization of energy savings.
3. Better performance from the utility's perspective, i.e. high power factor (>95%) and lower harmonic distortion (<10%).
4. No flicker, no hum, instant on.

The average load for the library building is about 810 kW when only one chiller is operating. The lighting load takes about 320 kW (39.5%) of the total load.

The existing lighting system with magnetic ballast and standard tube has been retrofitted with the following steps:

1. Install the reflector.
2. Change the magnetic ballast with electronic ballast.
3. Replace the standard tube with high output fluorescent lamp.
4. Reduce from 3 or 2 tubes per fitting to 1 tube per fitting.

The following sections will explain each of the steps.

A. Silverlux Reflector

All the light fittings, either 2 or 3 tubes are retrofitted to light fittings with single high output tube and 3M-SILVERLUX™ reflector. Before retrofit the light fitting were merely recessed painted casings that have a reflectivity of about 0.5. New fittings installed with SILVERFLUX™ reflectors having the reflectivity of 0.8, an increment of 60% light output compare to the old fitting.

B. Electronic Ballast

Lamp flicker common with most standard magnetic ballast is eliminated with electronic ballast. This is the result of running the lamp at 20kHz to 50kHz instead of the 50 or 60 Hz produced by magnetic ballast. An additional gain is the instant start-up of electronic ballast as compared to the longer inconvenient start-up time of magnetic ballast. It is also claimed that the lifetime of tubes is almost doubled with electronic ballast.

The selection of electronic ballast follows the items below:

- Total Harmonic Distortion (THD) of electronic ballast should be less than 20%.
- Power factor >95%.
- Lamp current Crest Factor less than 1.7.
- Minimum lamp starting temperature of -20°F to 50°F.
- Minimum 3 years warranty.
- Electronic ballast should operate at high frequency (>20 kHz) with minimum detectable flicker.

C. High Output Triphosphor Fluorescent Lamp

Triphosphor lamps offer a significant jump in lamp efficacy (76 - 91 lumens/watt) due to the increased efficiency of phosphor coating used in the tube. Triphosphor lamps offer advantages over standard phosphor lamps due to their higher Color Rendering Index (CRI), usually in 80's, while standard lamp typically in 60's and 70's. This translates into a more pleasant visual environment with less eyestrain.

The students feel that the light is dimmer though lux meter proved that there is sufficient light level for reading task. This is because the tube is a white light model which has a higher output in red color spectrum, that makes more comfortable for reading due to the lesser glare. The second reason is that eyes are adjusting to an new ambient light environment when they just enter from outside library.

D. Lighting Illuminance Level

The first phase of lighting retrofit was done for the 4th level only, mainly is the reading area. The overall pre-retrofit lighting power density is 1.8 w/ft2. It was brought down to 0.7 w/ft2 at reading and shelves areas after retrofitting with electronic ballast, reflectors and high output triphosphor fluorescent tubes.

TABLE 2
ILLUMINANCE LEVEL BEFORE RETROFIT CALCULATION

Before Retrofit Condition (efficiency of reflector is 0.5 for no reflector) Tube: TOSHIBA DAYLIGHT 36/2600 lm						
Tube	**Watt**	**Day Light (lm/w)**	**Lm/fitting**	**Qty**	**Total Lumens**	**Total Watt**
3	36	65	3,510	136	477,360	14,688
3	58	65	5,655	105	593,775	18,270
2	36	65	2,340	108	252,720	7,776
2	58	65	3,770	108	407,160	12,528
Total No Reflector					1,731,015	53,262
Total Summary						
Total Lumen	=	1,731,015.0	Lumens			
Total Area	=	30,122.0	Sqft			
Total watt per area	=	1.8	W/sqft			
Total lumen per area	=	57.5	Lm/sqft			
	=	618.0	Lux (lm/sqft x 10.76 lm/m^2)			

By applying electronic ballast, high output fluorescent tube and silverflux reflector, good illuminance level of about 450 lux can be achieved. A nominal suggestion for illuminance at reading tasks area is 400 to 450 lux, and 200 to 250 lux for bookshelf area. The lux level actually measured at the 4th floor retrofitted reading area is in the range of 420 lux to 750 lux with average of 607 lux and average of 203 lux at the shelf area. Tables 2 and 3 show the calculation of lighting illuminance level before and after retrofit of the 4th floor. The expected lux level for reading area is round 563 lux, while for the book shelves area is around 284 lux.

TABLE 3
ILLUMINANCE LEVEL AFTER RETROFIT CALCULATION

After Retrofit Condition (efficiency of reflector is 0.8; without reflector is 0.4)								
Tube	Reflector	Ballast	Watt	White Light (lm/w)	Lm/fitting	Qty	Total Lumens	Total Watt
1	1	1	36	92	2,649	165	437,085	5,940
1	1	1	58	95	4,408	138	608,304	8,004
Total with Reflector							1,045,389	13,944
1	0	1	36	92	1,324	77	101,948	2,772
1	0	1	58	95	2,204	75	165,300	4,350
Total without Reflector							267,248	7,122

Total with Reflector Summary			
Total Lumen	=	1,045,389.0	Lumens
Total Area	=	19,997.0	Sqft
Total watt per area	=	0.7	W/sqft
Total lumen per area	=	52.3	Lm/sqft
	=	563.0	Lux (lm/sqft x 10.76 lm/m^2)
Total without Reflector Summary			
Total Lumen	=	267,248.0	Lumens
Total Area	=	10,125.0	Sqft
Total watt per area	=	0.7	W/sqft
Total lumen per area	=	26.4	Lm/sqft
	=	284.0	Lux (lm/sqft x 10.76 lm/m^2)

TABLE 4
LUX LEVEL MEASUREMENT BEFORE AND AFTER RETROFIT.

Area	*Average Lux Level*		*Percentage Increase (%)*
	Before	After	
2nd Floor			
• Office	333	472	41.57%
• Staircase	160	270	68.75%
3rd Floor			
• Lobby	395	527.5	33.54%
• End Lobby	288	450	56.52%
• Meeting Room	370	350	-5.41%
• Staircase	160	300	87.5%
4th Floor			
• Book shelve	320	203	
• Reading area	510	607	
5th Floor			
• Windows area	747	943	26.34%
• Book shelve	254	474	86.70%
• Reading area	450	420	-6.67%

Then the lighting retrofit for 90% of the library was completed on July 1995 and the rest of it was completed on July 1997. The measured value for illuminance level area listed as Table 4. The reading were taken about 1 meter (3.3 feet) from floor level whereas light fitting is about 2.7 meters (9 feet) from floor level.

V. AIR HANDLING UNIT RETROFIT

There are two major reasons why the AHU retrofit need to be done for the library:

1. The library was too cold and humid, meaning too much air flowrates to the library.
2. The motors are oversized, meaning less efficient operation.

The two reasons coincide to each other for the benefit of AHU retrofit. The works included the following steps:

1. Replace old motors with new high efficient smaller rating motors.
2. Replace old fan and motor pulleys with the new appropriate ones.
3. Alignment the pulleys.
4. Readjustment of overload relay setting of the motors.

To make a proper calculation and measurement for getting the new size of motors and belts, and for the purpose of confirming the savings, the following data were taken:

1. Fan motor power consumption (in kW) and motor capacity (in hp).
2. Supply air flowrates (in fpm) to the AHU units.
3. Fan and motor rotation (in rpm).
4. Fan and motor pulley dimensions (in mm).
5. Return air wet-bulb (WB) and dry-bulb (DB) temperature to the AHU rooms. These temperatures represent the comfort level in the library at every level.

There are 3 AHU rooms located at each level of the library and each of them supply for approximate 1/3 of the each floor area. At each of the AHU room, the AHU box is located almost in the middle of the room equipped with the supply air washable filter in front of its cooling coil. The return air is freely return from the library hall to the AHU room above the AHU box. And the fresh air outlet with washable filter located at the wall just opposite the return air. Fig. 1 shows the AHU room diagram.

The step of sizing the motor of the air handlers starts with comparing the design airflow with the measured airflow. From this comparison, we can see that the pre-retrofit condition is over rated in terms of the airflow and this explains the cold and wet condition of the library. Further observation of the AHU room condition reveals that the fresh air supply to the AHU room was not enough. The following paragraphs explain the retrofit steps.

A. Airflow Consideration

The library has four levels and a total space of approximately 180,000 square feet. Three AHUs serve each level using a constant volume system. Design data from UTM indicated the design specifications as in Table 5. Air flowrate measurements were taken using Airflow propeller anemometer and shown in Table 6.

TABLE 5
AHU AIRFLOW DESIGN SPECIFICATIONS.

Level	*AHU #*	*Area (sq. ft)*	*Design Air flow (CFM)*	*(CFM/ sq. ft)*
2	1 to 3	50,500	53,300	1.06
3	4 to 6	48,900	47,000	0.95
4	7 to 9	44,200	51,000	1.15
5	10 to 12	35,900	55,200	1.54

TABLE 6
AHU AIRFLOW COMPARISON.

Level	*AHU #*	*Design Air flow (CFM)*	*Measured Air flow (CFM)*	*% Difference*
2	1 to 3	53,300	61,350	15%
3	4 to 6	47,000	59,900	27%
4	7 to 9	51,000	59,600	17%
5	10 to 12	55,200	66,050	20%
	Total	206,500	246,900	20%

Comparison of the measured air flowrates and the design values indicates that there is a potential to reduce air flowrates by 20% on average (see Table 6). The power used by the fan motor is proportional to the air flowrate cubed. Therefore, reducing the air flowrate by 20% (to the design flowrate) results in a reduction of fan power consumption to cubed of 20% of the current value, a potential saving of 60% and with the round up of the pulley size, this saving will be reduced by 5% to 20%. The consideration of pulley size will be explained in the next section.

B. Pulley Diameter Consideration

The AHU catalog has been used to select the appropriate motor size for the reduced air flowrate. For most of the motors, it reduces up to 50% (from 20 hp to 10hp), while some others reduce 25% (from 20hp to 15hp). There is a direct relationship involving motor pulley dimension and fan pulley dimension as stated below in (2). Table 7 shows the measured fan speed and pulley diameter for motor speed of 1450 rpm.

$$RPM_{mot} / D_{mot} = RPM_{fan} / D_{fan} \qquad (2)$$

Where

RPM_{mot} is motor speed, which constant of 1450 rpm;
RPM_{fan} is fan speed (rpm);
D_{mot} is motor diameter (mm);
D_{fan} is fan diameter (mm).

TABLE 7
FAN SPEED AND PULLEY DIMENSION.

AHU #	Pre-retrofit Fan Pulley D (mm)	Pre-retrofit Fan speed (rpm)	Pre-retrofit Motor Pulley D (mm)	Pre-retrofit Belt Type	Post-retrofit Fan Pulley D (mm)	Post-retrofit Fan speed (rpm)	Post-retrofit Motor Pulley D (mm)	Post-retrofit Belt Type
1	330	674	152	B-100	500	542	180	B-113
2	457	568	178	B-112	450	596	180	B-112
3	457	568	178	B-111	500	416	140	B-111
4	330	674	152	B-101	500	567	190	B-111
5	330	674	152	B-96	500	506	170	B-110
6	330	674	152	B-99	500	483	160	B-110
7	330	674	152	B-100	500	455	212	B-114
8	356	626	152	B-104	500	512	170	B-114
9	356	626	152	B-104	500	451	150	B-110
10	457	568	178	B-112	500	419	140	B-112
11	457	568	178	B-112	500	455	150	B-114
12	457	568	178	B-112	500	416	140	B-110

Those pulley dimensions adjust the savings gained from the retrofit exercise from estimated 60% to about 49% savings (a reduction of about 18%) as describe in the next section below.

C. Final Measurement Confirmation

The final confirmation of savings was taken on April 4 and 5, 1997 and compared the reading with the pre-retrofit data taken on March 27, 1997. The saving achieved is confirmed as 49%, from previously estimated of 60%. The 18% reduction of savings is due to adjusting the pulley size to the available commercially. Table 8 shows the pre and post-retrofit savings reductions.

TABLE 8
AIRFLOW AND SAVING CONFIRMATION.

Level	AHU #	Before Retrofit Air flow (CFM)	After Retrofit Air flow (CFM)	Airflow Reduction (%)	Before Retrofit Power (kW)	After Retrofit Power (kW)	Power Reduction (%)
2	1 to 3	61,350	58,500	5%	34.52	21.93	37%
3	4 to 6	59,900	46,050	23%	34.62	15.40	56%
4	7 to 9	59,600	51,650	13%	35.66	19.46	45%
5	10 to 12	66,050	59,050	11%	40.87	17.40	57%
	Total	246,900	215,250	13%	145.67	74.19	49%

TABLE 9
TEMPERATURE AND RELATIVE HUMIDITY.

Level	Pre-retrofit T-max (deg C)	Pre-retrofit T-min (deg C)	Pre-retrofit T-avg (deg C)	Pre-retrofit RH-avg (%)	Post-retrofit T-max (deg C)	Post-retrofit T-min (deg C)	Post-retrofit T-avg (deg C)	Post-retrofit RH-avg (%)
2nd	24.0	22.5	23.3	70	22.0	19.5	21.0	70
3rd	24.8	19.0	21.0	80	22.0	19.5	21.0	75
4th	21.5	18.5	20.0	80	21.5	19.0	20.5	75
5th	28.5	21.5	24.5	78	26.0	22.0	24.5	70

The library temperature is maintained and the relative humidity is reduced by 5-10%, drags the post-retrofit condition to the comfort zone in psychometric chart. This condition solves the issue of too cold and wet in the library and at the same time reduced the energy consumption. Table 9 shows the temperature and relative humidity condition of pre and post-retrofit.

VI. SAVINGS MEASURED

A. Phase I Savings

Phase I, which completed on November 1993, was a lighting retrofit at level 4 of the library. This was a test phase to verify efficiency and usability. A total of 56.94 kW is saved from the implementation of this energy saving measure. This is about 7% of the total building load (810 kW). The following paragraph will describe the calculation, matched with measurement, to achieve the saving.

1. Direct Savings

The electrical reduction calculation as shown at Table 10 and 11 thus gives the estimated electrical load reduction due to light retrofitting on 4h floor as given in (3) below.

$$\text{Estimated savings} = (68.345 - 21.066)\ \text{kW} = 47.28\ \text{kW} \qquad (3)$$

The measured data from before and after retrofit using *Enerlyst* system is shown in Fig. 2 and tabulated at Table 12 and 13 as given in (4) below.

$$\text{Measured savings} = (372.71 - 324.63)\ \text{kW} = 48.08\ \text{kW} \qquad (4)$$

TABLE 10
TOTAL LIGHTING LOAD BEFORE RETROFIT

Tubes/ fitting	Watts/ Tube	Ballast loss (W)	Fitting Nos.	Wattage (kW)
3	36	30	136	18.768
3	58	51	105	23.625
2	36	20	106	9.752
2	58	34	106	16.200
Total				68.345

TABLE 11
TOTAL LIGHTING LOAD AFTER RETROFIT

Tubes/ fitting	Watts/ Tube	Ballast loss (W)	Fitting Nos.	Wattage (kW)
1	32	4	242	8.712
1	52	6	213	12.354
Total				21.066

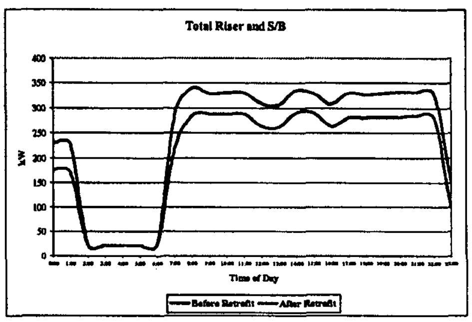

Fig. 2. Time-scale Monitoring Data.

As calculated from the data, electrical load reduction of 48.08 kW due to light retrofitting on 4th floor over 478 hours in November 1993. This shows ±1% agreement between calculation and measurement. It is also been noticed and agreed that there was no significant difference in air-conditioning load from August to November 1993.

TABLE 12
MAX COLLECTED LIGHTING LOAD DATA BEFORE RETROFIT

Date	*Electrical Riser-1 (kW)*	*Electrical Riser-2 (kW)*	*Electrical Riser-3 (kW)*	*Essential S/B (kW)*	*Total Load (kW)*
15-Aug-93	80.38	77.92	117.32	85.37	360.99
16-Aug-93	80.59	77.82	122.35	83.88	364.64
17-Aug-93	0	0	0	0	0
18-Aug-93	0	0	0	0	0
19-Aug-93	77.84	76.53	116.35	-	-
20-Aug-93	77.28	78.38	112.16	76.46	344.28
21-Aug-93	82.92	80.54	120.27	86.90	372.71
22-Aug-93	78.02	77.17	118.19	86.34	359.72
23-Aug-93	78.80	76.98	118.14	79.53	273.92
24-Aug-93	79.54	76.64	119.96	81.68	357.82
25-Aug-93	78.87	76.48	119.68	82.59	357.62
26-Aug-93	78.89	78.20	116.37	83.74	357.02
27-Aug-93	60.17	59.99	83.69	66.88	270.73
28-Aug-93	78.94	77.45	119.19	84.15	359.73
29-Aug-93	82.32	76.67	95.66	83.17	337.82
30-Aug-93	59.74	60.68	65.04	59.80	245.26
31-Aug-93	56.71	57.88	61.44	57.10	233.13
Max. Total Load					372.71

TABLE 13
MAX COLLECTED LIGHTING LOAD DATA AFTER RETROFIT

Date	*Electrical Riser-1 (kW)*	*Electrical Riser-2 (kW)*	*Electrical Riser-3 (kW)*	*Essential S/B (kW)*	*Total Load (kW)*
1-Nov-93	68.94	66.67	101.88	74.72	312.21
2-Nov-93	69.27	66.45	104.36	74.52	314.60
3-Nov-93	68.86	67.60	103.71	73.99	314.16
4-Nov-93	72.61	67.84	108.77	75.41	324.63
5-Nov-93	69.88	66.20	96.45	74.51	307.04
6-Nov-93	70.11	66.37	105.12	74.68	316.28
7-Nov-93	69.40	66.76	103.98	74.88	315.02
Max. Tot. Load					324.63

2. Indirect Savings

The chillers are set to operate alternately, normally chiller 1 for daytime during peak load period (07:00 – 15:00) and chiller 2 take over off peak period (15:00 – 24:00). Since the chillers are limited to run at low tonnage, it is not possible to view the reduction in chiller load. Therefore, the measured savings of 48.08 kW are translated to the cooling load tonnage directly, which is given in (5).

$$\text{Heat load Redct.} = 48.08 \text{ kW} \times 0.284 \text{ ton/kW} = 13.632 \text{ tons} \quad (5)$$

Using the data of the chiller nominal performance rating of 0.65 kW/ton, thus the reduction in chiller power is 8.86 kW as stated in (6), and the total savings is stated in (6).

$$\text{Chiller power Redct.} = 13.632 \text{ ton} \times 0.65 \text{ kW/ton} = 8.86 \text{ kW} \quad (6)$$

$$\text{Total Savings phase I} = (48.08 + 8.86) \text{ kW} = 56.94 \text{ kW} \quad (7)$$

B. Phase II Savings

Phase II completed the second, third, and fifth floor lighting (90%). The duration of this phase was from January 3, 1995 to June 20, 1995 and achieved 154 kW savings, which is another 19% of the total building initial load (810 kW). This phase and phase I, altogether bring 26% of savings. The lighting retrofit was maintained the same light level at most places except the staircase and book shaft areas where an improvement of 80% was achieved.

With the same method of savings calculation, Table 14 shows the power consumption measurement readings before and after the retrofit, which gives the savings as stated in (8).

$$\text{Lighting Savings phase II} = 129.96 \text{ kW} \quad (8)$$

The lower heat load due to the reduced lighting kW can be translated into less cooling load for the chiller system. Using existing chiller efficiency of 0.65 kW/Ton, which means (0.65/3.517 =) 0.185 kW chiller savings per kW used. Therefore, the chiller saving due to the lighting is stated in (9).

$$\text{Chiller Savings phase II} = 129.96 \times 0.185 = 24.04 \text{ kW} \quad (9)$$

The total savings is equal to the direct lighting savings and the indirect savings (displaced chiller kW) that is been stated in (10).

$$\text{Total Savings phase II} = 129.96 + 24.04 = 154 \text{ kW} \quad (10)$$

TABLE 14
MEASUREMENT OF LIGHTING RETROFIT FOR PHASE II

Building Level	*Power Usage (kW)*		*Savings (kW)*
	Before Retrofit	After Retrofit	
Level 2	90.96	36.77	54.19
Level 3	74.83	34.09	40.74
Level 5	60.44	25.41	35.03
Total	226.23	96.27	129.96

C. Phase III Savings

Phase III included the third phase lighting retrofit and the Air Handling Unit (AHU) retrofit. The number of AHU retrofitted totaled 12 units. The AHU retrofit was done in stages between March 12, 1997 to May 4, 1997. The pre-retrofit power data was taken on March 27, 1997 and post-retrofit on May 4, 1997, where both months consume the same air-conditioning loads. Phase III saved 23.06 kW (2.85% of the initial total building load) for the lighting retrofit and 84.70 kW (10.46% of the initial total building load) in the AHU retrofit. Total of phase III savings is 107.76 kW, which is 13.30% of the total initial building load.

Lighting measurement data is given at Table 15 and from that table, we can see the lighting savings achieved as mentioned in (11).

$$\text{Lighting Savings phase III} = 19.47 \text{ kW} \quad (11)$$

The lower heat load due to the reduced lighting kW can be translated into less cooling load for the chiller system. Using existing chiller efficiency of 0.65 kW/Ton, which means (0.65/3.517 =) 0.185 kW chiller savings per kW used. Therefore, the chiller saving due to the lighting is stated in (12).

$$\text{Chiller Sav. Fr. Lighting phase III} = 19.47 \times 0.185 = 3.6 \text{ kW} \quad (12)$$

The total savings is equal to the direct lighting savings and the indirect savings (displaced chiller kW) that is been stated in (13).

$$\text{Total Sav. Fr. Lighting phase III} = 19.47 + 3.60 = 23.06 \text{ kW} \quad (13)$$

TABLE 15
MEASUREMENT OF LIGHTING RETROFIT FOR PHASE III

Building Level	*Power Usage (kW)*		*Savings (kW)*
	Before Retrofit	After Retrofit	
Level 2	36.77	28.65	8.12
Level 3	34.09	27.99	6.10
Level 5	25.41	20.16	5.25
Total	96.27	76.80	19.47

Power consumption before and after AHU retrofit is given at Table 16, where the savings is calculated by subtracting post retrofit total to pre-retrofit total, given in (14). From 12 AHUs of initially 20-hp motors, 8 number of them have been replaced to 10-hp motors and the rest 4 of them to 15-hp motors (AHU 1, 2 7, and 8).

$$\text{AHU Savings phase III} = 145.67 - 74.19 = 71.48 \text{ kW} \quad (14)$$

Using the same formula to calculate chiller savings contributed from this 71.48 kW, given in (15).

$$\text{Chiller Sav. Fr. AHU phase III} = 71.48 \times 0.185 = 13.22 \text{ kW} \quad (15)$$

Therefore, the total saving from AHU retrofit is given in (16).

$$\text{Total Sav. from AHU phase III} = 71.48 + 13.22 = 84.70 \text{ kW} \quad (16)$$

TABLE 16
POWER CONSUMPTION OF AHU RETROFIT FOR PHASE III

AHU	Pre-retrofit absorbed power				Post-retrofit absorbed power			
	R-phase (kW)	Y-phase (kW)	B-phase (kW)	3 phase (kW)	R-phase (kW)	Y-phase (kW)	B-phase (kW)	3 phase (kW)
1	4.14	4.30	4.15	12.59	2.54	2.49	2.42	7.45
2	2.87	3.06	3.25	9.18	3.36	3.19	3.22	9.77
3	4.38	4.09	4.29	12.76	1.59	1.45	1.67	4.71
4	2.86	2.83	2.91	8.60	1.77	1.73	1.75	5.25
5	3.73	3.76	3.84	11.33	1.56	1.75	1.69	5.00
6	4.87	4.89	4.93	14.69	1.79	1.62	1.74	5.15
7	3.41	3.53	3.56	10.51	2.70	2.88	2.71	8.29
8	4.67	4.60	4.17	13.44	2.12	2.10	1.95	6.16
9	3.91	4.00	3.82	11.72	1.65	1.66	1.70	5.01
10	4.56	4.65	4.69	13.90	2.02	1.99	1.97	5.98
11	4.13	4.16	4.16	12.45	2.07	2.07	2.02	6.16
12	4.84	4.89	4.79	14.52	1.74	1.78	1.74	5.26
Total				145.67				74.19

Both savings of phase III from lighting and AHU retrofit then could be added as stated in (17).

$$\text{Total Savings phase III} = 23.06 + 84.70 = 107.76 \text{ kW} \quad (17)$$

D. Overall Savings

The overall retrofit exercises at the Library, including the lighting retrofits (phase I, II and III) and AHU retrofit, as stated from (7), (10) and (17), has achieved 318.70 kW, which is 39.35% of the total initial load (810 kW), as mentioned in (18). Table 17 shows the summary of combined savings.

$$\text{Total Savings} = 56.94 + 154 + 107.76 = 318.70 \text{ kW} \quad (18)$$

TABLE 17
THE OVERALL SAVINGS SUMMARY

Phase	Retrofit	Date Completed	Savings (kW)
I	Lighting at 4th floor	November 1993	56.94
II	Lighting at entire library (90% complete)	July 1995	154.00
III	Air Handling Unit	April 1997	84.70
	Completion of lighting	July 1997	23.06
Total			318.70

VII. CONCLUSION

The energy efficiency project on the UTM campus is a research project involving many aspects to quantify human response, comfort levels, user satisfaction and productivity as being the main feature of retrofit. Other effects of reducing energy usage include reduction of global warming effect, reduced expenditure by Public Utility (Tenaga Nasional Berhad) on power plant construction and a cleaner environment from emissions. The retrofit exercise generated savings of more than 300 kW, which is more than 39% of the total building load. More than 70% of these savings came from lighting retrofits. And with a 378 hours of operation of the library per month, the payback was lest than 2 years.

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IX. BIOGRAPHIES

Md Shah Majid (M'99) received his B.Sc degree in Electrical and Electronic Engineering from University of Strathclyde in 1980 and M.Sc in Power System Analysis from University of Manchester Institute Science and Technology, United Kingdom in 1985. Currently, he is an Associate Professor in the Faculty of Electrical Engineering, Universiti Teknologi Malaysia. His research interests include energy efficiency, demand side management and its environmental impact and application of control schemes to power system.

Faridah Mohd. Taha (M'99) currently is an Associate Professor in the Faculty of Electrical Engineering, Universiti Teknologi Malaysia. Her research interests include energy efficiency, demand side management and its environmental impact and application of control schemes to power system.

Noor M. Maricar (S'87) received his MS in Electrical Engineering from Illinois Institute of Technoogy and M.Sc in Computer Integrated Engineering from Nanyang Technological University, Singapore, in 1998 and 1997 respectively, and his B.Sc degree in Electrical Engineering from Institut Teknologi Bandung, Indonesia in 1993. Currently, he is a graduate student at Virginia Polytechnic Institute and State University.

Saifur Rahman (S'75, M'78, SM'83, F'98) is the Director of Alexandria Research Institute at Virginia Tech where he is a professor of electrical engineering. He also directs the Center for Energy and Global Environment at the university. Dr Saifur Rahman is currently serving on the Power Engineering Society Governing Board as the Vice President for Education/Industry Relations. He serves on several PES committees and subcommittees including the Education Committee, Energy Development Subcommittee and Consumer Products and Services Subcommittee. He is also a member-at-large of the IEEE-USA Energy Policy Committee. He has published over 200 papers on conventional and renewable energy systems, load forecasting, uncertainty evaluation and system planning.